160 Gbit/s all-optical SOA-based wavelength conversion and error-free transmission through two 50km fibre links

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160 Gbit/s transmission through a 50 km fibre link followed by 160 Gbit/s all-optical SOA-based wavelength conversion, and subsequently the converted 160 Gbit/s signal is successfully transmitted through another 50 km fibre link, is demonstrated. Error-free operation is achieved with acceptable penalty levels in the whole experimental system.

Introduction: All-optical wavelength conversion that utilises the nonlinearity of semiconductor optical amplifiers (SOAs) is a promising technology for the application in fast reconfigurable optical interconnects and switching fabrics in wavelength-division-multiplexed networks [1, 2]. To overcome the slow recovery time of the SOA, optical filtering technology is used to enhance the operating speed of the SOA [3, 4]. Error-free 320 Gbit/s wavelength conversion has been achieved by this way [5], where optical filtering is used to select the blue sideband of the optical spectrum of the converted signal. However, such an optical filtering based wavelength conversion has not been tested in the field of fibre transmission. In this Letter, we investigate the performance of such a high speed wavelength conversion in the fibre transmission. For this purpose 160 Gbit/s data signal is first transmitted through a 50 km singlemode fibre (SMF) link, and is subsequently converted to a new wavelength using an SOA assisted by an optical filter. The converted 160 Gbit/s signal is successfully transmitted through another 50 km SMF link. Error-free operation with acceptable penalty levels is achieved in the whole experimental system.

Experimental setup: Fig. 1 depicts the setup used in the experiment. It consists of a 160 Gbit/s OTDM transmitter, two 50 km SMF links with dispersion compensation fibre (DCF) and an all-optical wavelength converter in between the two fibre links. In the transmitter, a 10 GHz 1.6 ps return-to-zero pulse, generated by an actively modelocked fibre ring laser at 1546 nm, is modulated to form a 10 Gbit/s $2^7 - 1$ pseudorandom binary sequence (PRBS) pattern. The modulated 10 Gbit/s PRBS signal is increased to 160 Gbit/s using four passive-fibre time-interleavers, which are matched for $2^7 - 1$ PRBS. The 160 Gbit/s data signal is amplified by EDFAs before the signal is launched into the fibre links. The input signal power is 8 dBm for the two 50 km SMF links. After each link, chromatic dispersion is managed using broadband dispersion compensation modules of 862 and 857 ps/nm. Some extra SMF is required after the DCF to match the total cumulative dispersion (required accuracy is around 0.2 ps/nm or about 20 m of SMF), namely 2.4 and 2.2 km.

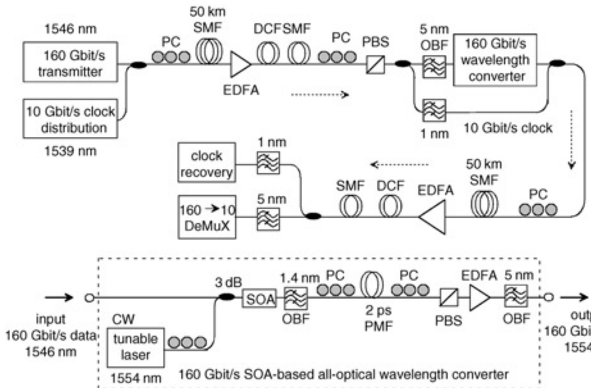

Fig. 1 *Experimental setup*

Dashed box shows configuration of 160 Gbit/s optical wavelength converter

In the first 50 km fibre link, polarisation mode dispersion is also compensated using polarisation controllers (PCs) and a polarisation beam splitter (PBS) after the SMF link. The PBS is not required in the second 50 km fibre link, since the light is polarised by the optical wavelength converter. EDFAs are used to compensate for the transmission link and dispersion compensation losses, about 15 dB each. In the all-optical wavelength converter, the signal is converted to 1554 nm.

The dashed box in Fig. 1 shows the configuration of the wavelength converter, which is constructed using commercially available fibre-pigtailed components. It is shown in [4] that this configuration allows error-free non-inverted wavelength conversion at 160 Gbit/s. Both the data signal and continuous-wave (CW) output from a tunable laser are fed into the SOA to achieve inverted wavelength conversion based on cross-gain modulation. The biasing current for the SOA is 400 mA. A 1.4 nm optical bandpass filter (OBF) is placed at the output of the SOA. The centre wavelength of the OBF is 1.23 nm blue-shifted with respect to the centre wavelength of the CW light. The 1.23 nm blue-side detuning is essential because the detuning of the OBF allows utilisation of ultrafast chirp dynamics in the SOA, and suppression of the slow gain recovery of the SOA. Thus the recovery time of the wavelength converter can be shortened to less than 3 ps, which ensures the pattern-independence of 160 Gbit/s wavelength conversion [4]. A delay interferometer, implemented with PCs and polarisation-maintaining fibre (PMF), is used to flip the polarity of the converted signal after the SOA from inverted to non-inverted signal.

In addition, the 10 Gbit/s original signal is transmitted out-of-band at 1539 nm as clock reference. The clock and 160 Gbit/s data signal are combined prior to launch to the fibre and separated by optical bandpass filters in the intermediate point and at the receiver side. At the receiver side, the clock signal is detected and launched into a phase-locked loop which drives a 160 to 10 Gbit/s optical demultiplexer. The demultiplexer is implemented with two cascaded electroabsorption modulators which generate a 5 ps gating window. The demultiplexed signal is fed into a bit error rate (BER) tester for analysis.

Experimental results: Fig. 2 shows the eye diagrams of 160 Gbit/s signal at different points of the system. The eye diagrams are measured by an optical sampling scope with 700 GHz bandwidth. Fig. 2*a* shows the transmitted optical signal. Fig. 2*b* depicts the signal after the first 50 km fibre link and the dispersion compensation stage. The eye diagrams are widely open but with slight degradation and broadening, mainly due to accumulated noise and optical filtering. Fig. 2*c* presents the eye patterns of the wavelength converted signal, where the optical pulses are broadened to be about 4 ps owing to the narrow optical filtering in the wavelength conversion [4]. Clear open eyes are observed. The converted signal is transmitted through the second 50 km fibre link. Eye diagrams are shown in Fig. 2*d*, where further degradation is observed, but the eyes are clear open.

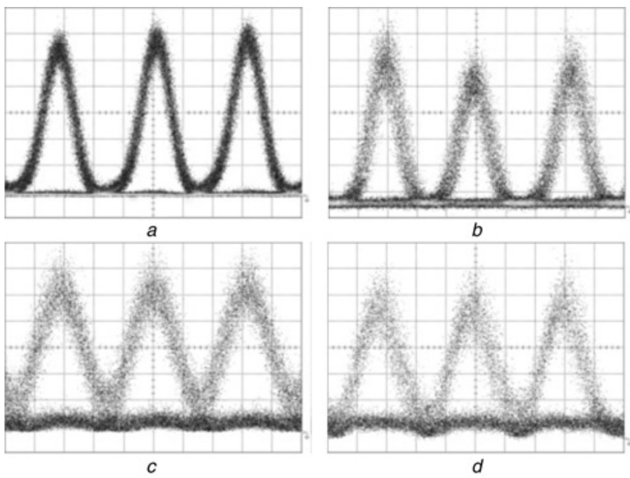

Fig. 2 *Eye diagrams of 160 Gbit/s signal across system (2 ps/div.)*

a At transmitter
b After first 50 km fibre link
c After 160 Gbit/s wavelength conversion
d After second 50 km fibre link
Eye diagrams measured by 700 GHz optical sampling scope

Fig. 3 shows the BER measurements of the 160 Gbit/s signal. All 160 Gbit/s tributary channels are presented, the linear fits and the experimental results. Each linear fit corresponds to one tributary channel.

In addition, the 10 Gbit/s basic channels that are multiplexed to the 160 Gbit/s data stream are presented in Fig. 3*a*. The associated eye diagram is depicted in Fig. 3*b*. For the back-to-back performance, BER results of the 160 Gbit/s input signal are presented in Figs. 3*c*, and Fig. 3*d* shows the associated demultiplexed eye diagram. Figs. 3*e* and *f* present the BER curves and the eye diagram after the converted signal is transmitted through the total two fibre links. It can be observed from Fig. 3*e* that error-free operation is achieved for all 16 tributaries without using forward error correction (FEC). The average sensitivity penalty through the whole fibre link at BER = 10^{-9} is about 6 dB with respect to the original 160 Gbit/s back-to-back transmission. The deviation between the linear fit and the experimental results show an error-floor around BER = 10^{-12}. This is mainly because the converted pulses are too broadened for the gating window in the demultiplexer, leading to crosstalk between adjacent time channels but also because of signal-to-noise degradation. This can be solved by using signal regeneration [6, 7].

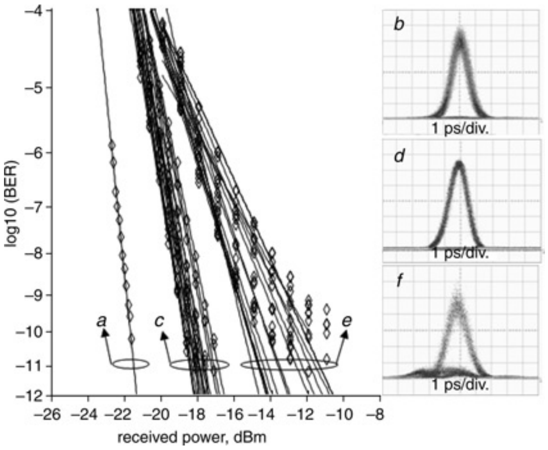

Fig. 3 *BER curves and associated demultiplexed eye diagrams of: 10 Gbit/s original channel (Figs. 3a, b), back-to-back situation (Figs. 3c, d), and transmission through the whole two 50 km fibre links (Figs. 3e, f)*

Conclusion: 160 Gbit/s all-optical wavelength conversion based on an SOA assisted by optical filtering in combination with fibre transmission through two 50 km SMF links has been demonstrated. Error-free operation with acceptable penalty levels is achieved for all channels without using FEC.

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